# Modeled Climate Change Impacts in the Abbotsford-Sumas Aquifer, Central Fraser Lowland of BC, Canada and Washington State, US.

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## Abstract

This paper presents the results of climate change impacts modeling in the Abbotsford-Sumas aquifer in coastal British Columbia and Washington State. A three dimensional transient groundwater flow model, implemented in Visual MODFLOW, was used to simulate three climate scenarios in one-year runs (1961-1999 present, 2010-2039, 2040-2069) in order to compare recharge and groundwater levels to present. Weather inputs for recharge modeling were generated with the LARS stochastic weather generator using statistically-downscaled CGCM1 global climate model results. The downscaling dataset was calibrated to local historical data. Recharge was modeled in HELP and accounted for unsaturated zone depth, heterogeneity, and soils. Water table elevation differences were computed at each time step of the climate scenario model runs for historical and future predicted climates, then mapped in GIS. Recharge to the Abbotsford-Sumas aquifer is predicted to decrease by 5.6 to 6.3% relative to historic values under climate change for the 2010-2039 scenario, resulting in a spatially-variable reduction in water levels ranging from 0.05 m to more than 0.25 m in most upland areas. For the 2040-2069 time periods, recharge decreases by 12.7 to 14.6% relative to historic values, resulting in water level declines greater than 0.25 m in most upland areas. These lower water levels will result in a reduction in hydraulic gradients from recharge to discharge areas, and a consequent scaled reduction in groundwater discharge. Because upland streams were assigned as constant head boundary conditions, the model does not predict significant changes in areas adjacent to the streams nor to the streams themselves. The preliminary results suggest that flow rates into streams and ditches are of approximately the same magnitude as observed streamflows, but the lowering of water table in the uplands would most likely decrease baseflow in the streams fed mostly by seepage of groundwater.

## Introduction

Water resources are central to any study on climate change; however, most research to-date has been directed at forecasting the potential impacts to surface water hydrology (e.g., Whitfield and Taylor 1998). Relatively little research has been undertaken to determine the sensitivity of groundwater systems to changes in critical input parameters, such as precipitation and runoff. It is expected that changes in temperature and precipitation will alter groundwater recharge to aquifers, causing shifts in water table levels in unconfined aquifers as a first response to climate trends (Changnon et al 1988; Zektser and Loaiciga 1993).

This paper describes the results of a climate change impacts modeling study in the Abbotsford-Sumas aquifer. The aquifer is located within the Fraser and Nooksack River lowlands in the central and eastern Fraser Valley in southwest British Columbia (BC) and northern Washington State (WA) (Figure 1). The aquifer is mostly unconfined and is located on a broad outwash plain, which is elevated above the adjacent river floodplains. Small streams drain area. The aquifer is highly productive, is bisected by the international boundary, and provides water supply for nearly 10,000 people in the US (towns of Sumas, Lynden, and farmlands) and 100,000 in Canada, mostly in City of Abbotsford, but also in township of Langley. The coastal climate is humid and temperate, with large rainfall over most of the year.

The approach consisted of constructing a 3 dimensional groundwater flow model for the aquifer, modeling spatially-distributed and temporally-varying recharge based on the historic climate scenario, and then calibrating that model to historic water levels. For the climate scenarios, recharge values for future climate change scenarios were modeled and input into the model, and the impact on water levels in the aquifer were calculated. The methodology is consistent with that used by Allen et al (2004) for the Grand Forks aquifer in south central BC.

## Geological Framework and Hydrostratigraphic Model

The following description of the geological framework for the Abbotsford-Sumas aquifer and the Fraser Lowland is summarized from various geological and hydrogeological reports (e.g., Clague et al 1998; Cox and Kahle 1999;

Halstead 1977; Kahle 1991; Ricketts et al 1993) as well as from examination of many thousand borehole lithology logs from drilled water wells in the region.

**Figure 1** (a) Regional location map of the model area in British Columbia and Washington State. (b) Central Fraser Valley location map showing model area, cities and towns, topography, international border, and major rivers. White dotted outline shows model boundary, which encompasses the Abbotsford-Sumas aquifer. (c) Streams and rivers of central Fraser Valley, draining the Abbotsford-Sumas aquifer system, and locations of streamflow gauges.
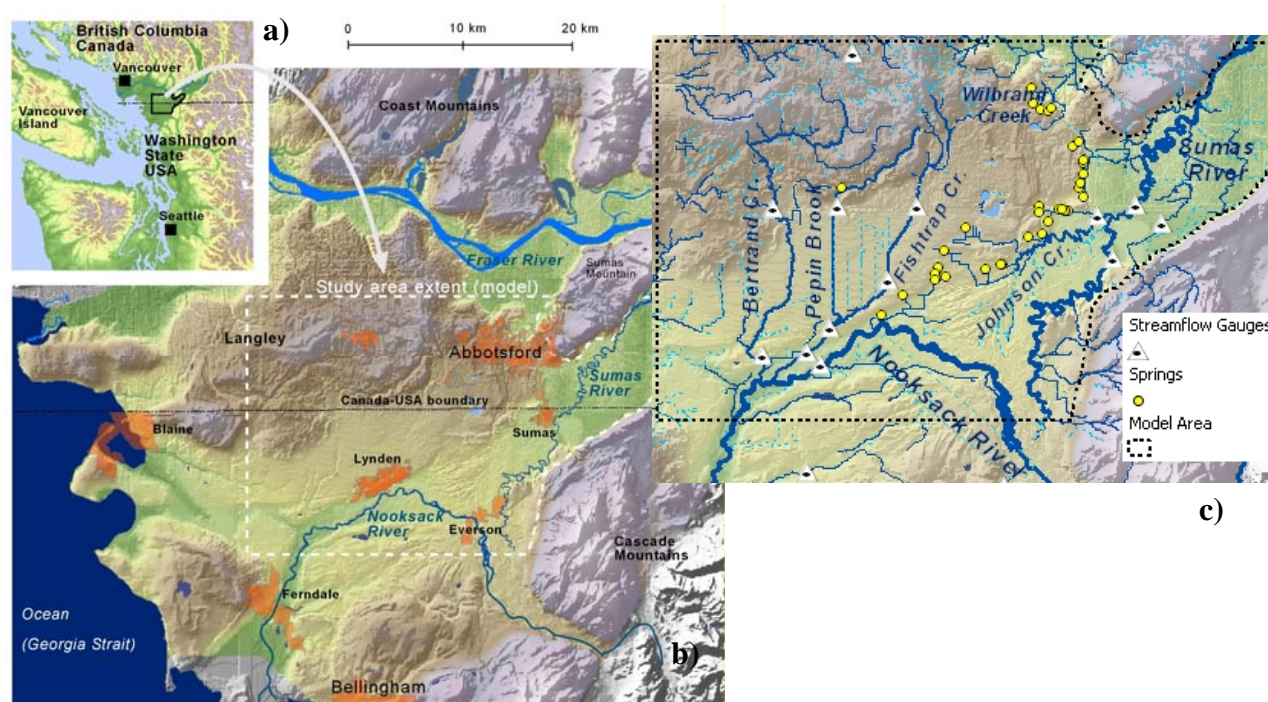


The Fraser Lowland consists of rolling hills of glacial drift, 60 to 120 m above broad valley floors. The floodplains are currently near sea level. The valley fill consists of complex sequences of diamictons and stratified drift, in various associations with marine and deltaic sediments, showing complex structure and chronology of deposition (Armstrong 1981). These sediments had a complex depositional history during the Wisconsin glaciation of the Pleistocene period, during which the lowland experienced repeated glacial and interglacial events.

The Abbotsford-Sumas aquifer is mostly unconfined and is composed of uncompacted sands and gravels of the Sumas Drift, a glacial outwash deposit. There is significant heterogeneity of the hydrostratigraphic units, which likely results in complex groundwater paths, particularly at a local scale. The aquifer is underlain by extensive glaciomarine deposits, generally described as glaciomarine stony clays, which are found near ground surface in the Langley area west of the Abbotsford-Sumas aquifer, and interpreted to underlie the surficial aquifers. Laterally, the valley sediments are confined by the Tertiary bedrock surface, which outcrops as mountains on both sides of Sumas Valley, and as small outcrops south of Nooksack River. The elevation of the Tertiary bedrock surface beneath the Pleistocene deposits of the lowland varies considerably, indicating pre-glacial erosional topography with large relief (Easterbrook 1969). Near Abbotsford, BC there is about 300 to 500 m of accumulated Pleistocene sediment overlying bedrock. A digital representation of the Tertiary bedrock topography was generated using deep borehole data, existing bedrock contour maps (Hamilton and Ricketts 1994), valley wall profiles, offshore bathymetric contours, and extrapolated cross-sections through the study area. This surface is considered relatively impermeable and serves as an effective lower boundary to groundwater flow.

Due to the significant heterogeneity of the sediments and the questionable quality of water well records, the traditional approach of constructing cross-sections by interpolating lithologies between boreholes to create a solid model was not possible. This approach invariably led to a "smoothed and homogenized" representation of the stratigraphy because layers could not be clearly identified. An alternative approach involved examining clusters of

boreholes and mapping the lithologies as hydrostratigraphic unit zones (K-zones) directly into MODFLOW. This involved defining, on a layer by layer basis, property zones in Visual MODFLOW (WHI 2000) that would correspond to similar hydraulic properties (K and $S_s$). Geographical Information System (GIS) data visualization allowed conjunctive viewing of borehole lithologs, surficial geology maps, ground and bedrock surfaces, and MODFLOW grid layers (mostly planar surfaces). Due to the complexity of the stratigraphy, no unique representation was possible, thus the mapped geology is analogous to one "realization" of a stochastic geologic interpolation in 3D. Notwithstanding, the final representation was based on local geological and hydrogeological interpretations as reported in the published literature. Figure 2 shows the hydrostratigraphic units for layer 3 of the MODFLOW model, and highlights the high degree of heterogeneity that can be captured using this alternative mapping method.

**Figure 2** (a) Map of hydrostratigraphic units in layer 3 and (b) cross-section from W to E in central region.
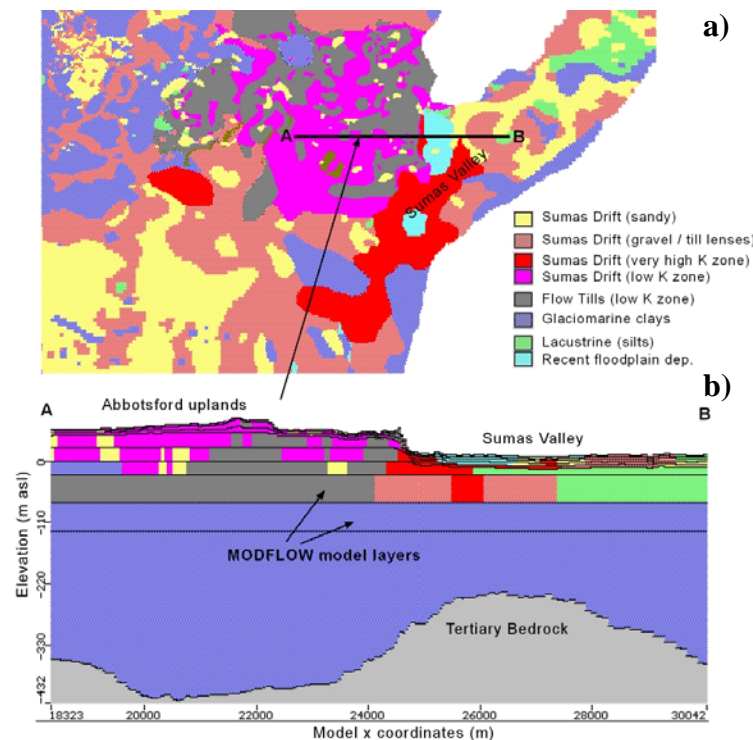


Each K-zone represented in the model was then assigned a unique hydraulic conductivity (K) and specific storage ($S_s$) value. There is extensive pump test and specific capacity data for the US side of the model, but sparse information on Canadian side. Thus, mean values were calculated from the US dataset for each hydrostratigraphic unit (sampled at well screen location), and the properties extrapolated to areas with poor pump test data. K and $S_s$ data are observed to have a heterogeneous distribution, and strong zonation in some areas.

The initial model calibration attempts indicated that there were areas with large residuals, which did not respond to changes in K within the reasonable range for each mapped K-zone. In those areas, the geology was re-interpreted from borehole lithologs, this time with much more attention given to possible interpretations, keeping in mind the model residuals, surficial geology, and looking at individual borehole records to verify standardized lithologic units. In many areas, there are many possible interpretations of local geology due to poor distribution of boreholes. The primary problem with the lithology dataset is the uneven distribution of deep boreholes; some areas rely exclusively on interpolated hydrostratigraphic units, which could be interpreted differently. As much care as possible was taken to locally calibrate this model, and to repeatedly review the hydrostratigraphic unit distributions and adjust the hydraulic conductivity values accordingly. The interpretation favouring the lowest possible model residuals was selected, and the geology re-mapped in that area. Therefore, the groundwater flow model provided a feedback to the interpretation of geology in areas with poor distribution or low quality of borehole data.

## Climate Scenarios

Climate scenarios for modeled present and future conditions were taken from the Canadian Global Coupled Model (CGCM1) (Flato et al 2000) for the IPCC IS92a greenhouse gas plus aerosol (GHG+A) transient simulation. Daily data sets for CGCM1 were downloaded from Canadian Institute for Climate Studies (CICS). These include absolute and relative changes in precipitation, including indirect measures of precipitation intensity, dry and wet spell lengths, temperature, and solar radiation. Climate data were downscaled using Statistical Downscaling Model (SDSM) software (Wilby et al 2002; Yates et al 2003). Downscaled data were calibrated to observed historic climate data. Three year-long climate scenarios were generated using the calibrated downscaled model, each representing one typical year in the present and future (2020s and 2050s): current climate (1961-1999), 2020's climate (2010-2039), and 2050's climate (2040-2069). Daily weather was generated using the LARS-WG stochastic weather generator (Racsko et al 1991; Semenov et al 1998). In this study, only the effects on groundwater levels of changes to recharge are considered.

## Recharge Modeling

Aquifer recharge was generated as spatially-distributed and temporally-varying recharge zonation (Allen et al 2004) using GIS linked to the one-dimensional HELP (Hydrologic Evaluation of Landfill Performance). HELP is a hydrologic model developed by USEPA (Schroeder et al 1994) and the code is contained in UnSat Suite software (WHI 2000). The approach used for recharge modeling is similar to that of Jyrkama et al (2002), in which a methodology was developed for estimating temporally varying and physically based recharge using HELP for any MODFLOW grid cell. Our method differs from previous distributed-recharge methods in that we also estimate the distribution of vertical saturated hydraulic conductivity in the vadose zone and the thickness of the vadose zone at high spatial resolution. A total of 64 unique recharge zones were defined based on classed soil column properties, and recharge was estimated for each. All map processing was done on 20m raster grid cells. The temporal inputs are derived from the LARS-WG stochastic weather generator, as opposed to WGEN (internal weather generator in UnSat Suite), and as derived from downscaled CGCM predictions.

Recharge estimates that were based on soil type, vadose zone property, and mean annual rainfall were subsequently adjusted for the observed precipitation gradient (Figure 3). The precipitation map was computed as percent difference in mean annual precipitation to that recorded at the Abbotsford Airport, which was used as the index station for climate change scenario forecasts. Thus, all recharge estimates were adjusted proportionally by the same percent difference, assuming that recharge is directly proportional to precipitation for any given recharge zone. This is the simplest method of such calculation, otherwise the inputs to the HELP model would have to be estimated for all locations of the model prior to determination of recharge zones by the HELP model output. The overriding assumption is that the precipitation gradient is similar throughout a "typical" year. The gradient magnitudes are different in the 12 months, but gradient direction should be similar to mean annual precipitation gradient.

## Surface Hydrology and Groundwater Levels

The largest valley in this area is the Sumas Valley, which runs north-east to south-west and contains the lower drainage of the Sumas River (Figure 1c). Sumas River flows to the northeast and picks up a significant baseflow component from aquifer discharge on its eastern side. To the south is the Nooksack River, flowing to the west and then south, and draining most of southern drainage. It has baseflow contributions from the Abbotsford-Sumas aquifer, as well as from the aquifers to the south. Most of the surface and groundwater flow from the Abbotsford-Sumas aquifer ends up in the Nooksack River. To the north, the model area includes a portion of the Fraser River floodplain. Several sizable creeks drain to the north, but the quantity of groundwater traveling north is considerably less than that flowing south and west.

The previous investigations in Washington State on streams draining the Abbotsford uplands established that the baseflow component is very high, between 70 and 95% of stream flow in large creeks such as Fishtrap Creek. Knowing this and the fact that the stream channels are strongly hydraulically linked with the aquifer, the question arises as to what boundary condition is most appropriate for the groundwater flow model along these streams. In the upper reaches of the streams, such as Fishtrap Creek, the stream bed is often perched above the regional water table. In the lower reaches, the stream receives large inflow from groundwater.

**Figure 3** (a) Mean annual precipitation gradient in the lower Fraser Valley and (b) map of mean annual recharge to aquifer.
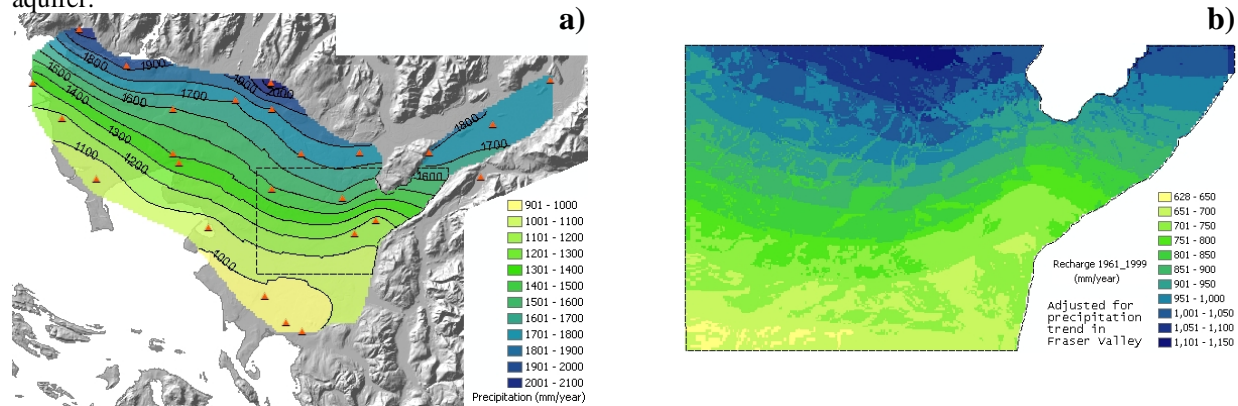


Groundwater elevations change by 2 to 4 m seasonally, away from the streams, according to observation well hydrographs. However, stream water elevations vary by much less, although streamflow does change seasonally. Thus, it is unlikely that changes in streamflow in a creek such as Fishtrap Creek would affect groundwater elevations in the adjacent aquifer. Over most of the stream distance, the stream gains baseflow from the aquifer at an average rate of 0.025 $m^3$/s/km channel length. Therefore, the streams can be represented as specified head boundaries, such that the head schedules will represent the modeled river stage in transient aquifer model. The term "constant head" and "specified head" are equivalent here because the head is "constant" for the duration of a time step, but then is specified to change to different value with time. Those lakes that have gauges were modeled as constant (specified) head boundary condition, where a schedule of head values (monthly) could represent the water level in the lake. Other lakes were assigned constant head values for average surface water elevation.

Larger rivers such as Sumas and Nooksack Rivers have seasonally changing discharge and stage hydrographs. However, most of the hydraulic heads in the aquifer above the river floodplains are not affected by changes in river stage, only the adjacent areas to the river are affected. It is a simplification in the model to represent the larger valley rivers as constant head boundary conditions, without temporally varying stage hydrograph, but as the groundwater flow model covers mostly aquifer area above the valley floodplains and the larger rivers, the assumption of constant head in the larger rivers will not affect model results in those upland areas even in transient model. Drain boundary conditions were used for large ditches and ephemeral streams. Drains were used only in areas where the calculated heads were too high above ground (or lake) surface, and drains were used to tie-in the water table elevations to lake and drain elevations.

Groundwater level records number in thousands in the Fraser Valley. The datasets that were selected include all static water levels in BC well database, all available United States Geological Survey (USGS) and WA Ecology well records, transient water observations from piezometers and observation wells monitored by Environment Canada (south of Abbotsford Airport), USGS, WA Ecology, and others. A total of 2958 wells with static water levels were used for calibration of the steady-state model. These wells include all of the domestic water wells, of varying depth, and major production wells. The wells have an even spatial distribution across the aquifer, and thus, provide an excellent means for steady-state and model calibration. It is important to recognize however, that the water elevations used for model calibration were determined at the time of drilling, and therefore, may not be representative of current groundwater conditions. In this respect, the ability of the model to accurately represent local detail is lower that it would be had the calibration data and stream elevation data been collected at the same instant in time. Most of the observation wells have very similar temporal variation in groundwater levels. The water table elevation is highest from February to April, then declines in elevation at non-linear rate until August, when the rate of decline becomes smaller. The minimum groundwater levels occur between September and November. In December, or as early as November, the increased precipitation (in wet years) causes a rise in water table again. At most locations sampled, the amplitudes of the groundwater level hydrographs is between 2 and 3 meters.

## Model Results

The effects of climate change are difficult to observe on head distribution maps because the highly variable and localized hydraulic gradients in the central Fraser Valley dominate all other trends. The climate-induced changes in water elevations are on the order of less than 0.25 m (25 cm) in most areas, but are up to 2 m in sensitive areas in Abbotsford uplands. The water table elevation in the valley ranges from near 0 to above 80 m above sea level (masl) elevation, so any changes cause only a slight shift the water table contours. Thus, it was necessary to develop a different strategy for displaying any changes induced by climate, which would exclude the hydraulic gradient within the aquifer, and compare directly changes from present conditions. Accordingly, head difference maps were prepared to show only differences due to climate change between future climate scenario model outputs and present climate scenario model outputs. The pumping effects were also subtracted out in these maps because drawdown was identical in all climate scenarios (pumping rates were constant in all models for the pumping time period).

Instead of using discrete head values at points (wells), the water table elevation map was used for climate change comparisons. The model layer surfaces are very irregular near the ground surface, and the use of HUV package in MODFLOW 2000 and 3D raster-grid approach to hydrostratigraphic unit mapping does not predispose head maps "by model layer" to be used in this case. In layers 1 to 4, there are large areas with dry cells (no head value available), and only in Layer 5 are there mostly wet cells in the model. However, the water table lies in layer 1 to 2 in Abbotsford and Langley uplands, then transitions through layer 3 and 4 to layer 5 in Sumas Valley. Head maps would show some confined and unconfined areas blended together.

## Impacts of Climate Change on Recharge and Groundwater Levels

Figure 4 shows the predicted changes in aquifer recharge for each of the 2010-2039 and 2040-2069 climate change scenarios. Results are expressed as a percent difference from this historic time period (1961-1999). Both scenarios indicate a reduction in recharge. The 2010-2039 scenario shows a reduction in recharge by 5.6 to 6.3% relative to historic, while the 2040-2069 scenario shows a reduction in recharge by 12.7 to 14.6% relative to historic. Figure 5 shows difference in water levels across the aquifer relative to historic for different times in the transient model and for each of the 2010-2039 and 2040-2069 climate scenarios. Two trends are apparent at all time steps and for all scenarios. As forced by recharge, the water table elevations did not change immediately along river channels where streams, rivers, and lakes were defined as constant head boundary conditions in the model. By definition, constant heads in a flow model do not change. There would be no change expected unless the streams and rivers dried up, or if the timing and magnitude of peak flow changed in the transient model (not simulated here in a transient model). Where streams were defined as drains, the water levels were free to vary. The second observation is for areas away from the rivers; here large spatial differences in water level change are observed.

**Figure 4** Predicted changes in recharge to aquifer as percent difference maps from (a) 2010-2039 climate scenario to present, (b) 2040-2069 climate scenario to present.
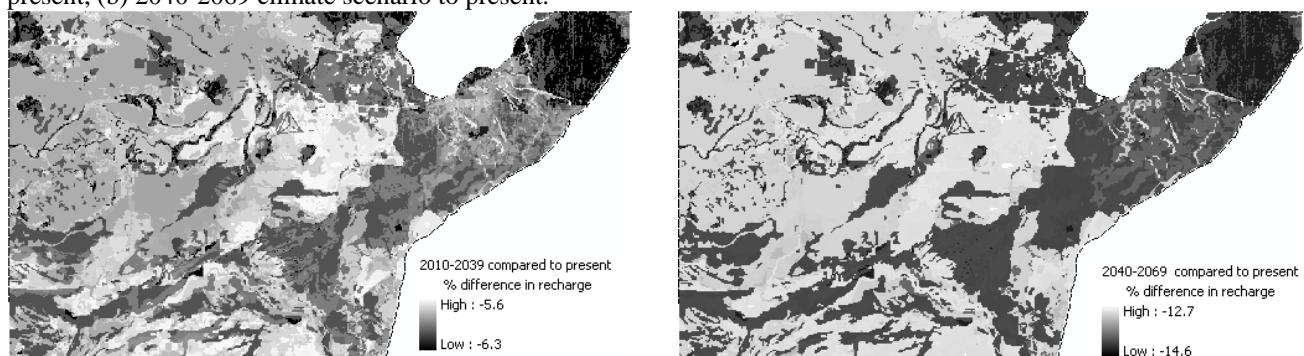


Uplands: In the Abbotsford uplands, except in a few pockets around lakes and streams, the groundwater levels were predicted to decrease by between 0.05 m to more than 0.25 m due to climate change by the 2010-2039 period. In certain localized areas, such as areas with suspected perched water tables and or poor model calibration, the model predicted very large changes, on the order of 10 m, but those results may be spurious due to questionable calibration. The decrease in groundwater levels was even greater in the next climate scenario 2040-2069, such that in the

Abbotsford uplands, decreases were greater than 0.25 m in most areas. In the Langley uplands, including areas adjacent to the Brookswood aquifer (west), the decreases were smaller in magnitude than in the Abbotsford uplands. In the Langley area, in the 2010-2039 scenario, the groundwater levels dropped by 0.05 to 0.10 m, and in 2040-2069 scenario, dropped by 0.10 to 0.25 m.

Lynden Terrace: The flat and undulating outwash plain north of Lynden, WA, between south flowing Bertrand Creek and Fishtrap Creek, was predicted to have small decreases in water levels (less than 0.10 m). Creeks in that area might be expected to have lower baseflow as a consequence of the predicted lower groundwater levels in the aquifer. Secondly, with lower groundwater levels, the streams could loose water to the aquifer (effluent streams) at certain times of the year due to a reversal in hydraulic gradient. In order to determine the impact of climate change on these streams, it would be necessarily to investigate the existing aquifer-stream connection at different locations and, using the model, explore how the interactions might change.

River Valleys and Floodplains (lowlands): The model has excellent calibration in these areas due to the fact that the valley floor and water table surfaces are flat and because the heads are constrained by the imposed constant head boundary conditions. These are discharge areas of the aquifer, and changes in recharge due to climate change did not produce any noticeable changes in water table elevations in these areas. Preliminary results suggest that flow rates into the streams and ditches are of the same magnitude as observed streamflows. Nonetheless, the lowering of water table in the uplands would most likely decrease baseflow in the streams fed mostly by seepage of groundwater.

**Figure 5** Water level differences of the modeled water table at days 91 and 274 between future and present climate (a) scenario 2010-2039 and (b) scenario 2040-2069. Values were reclassified to range from 0 to -0.25 m. Values of -0.25 in discrete areas have changes between -0.25 and -3.0 m.
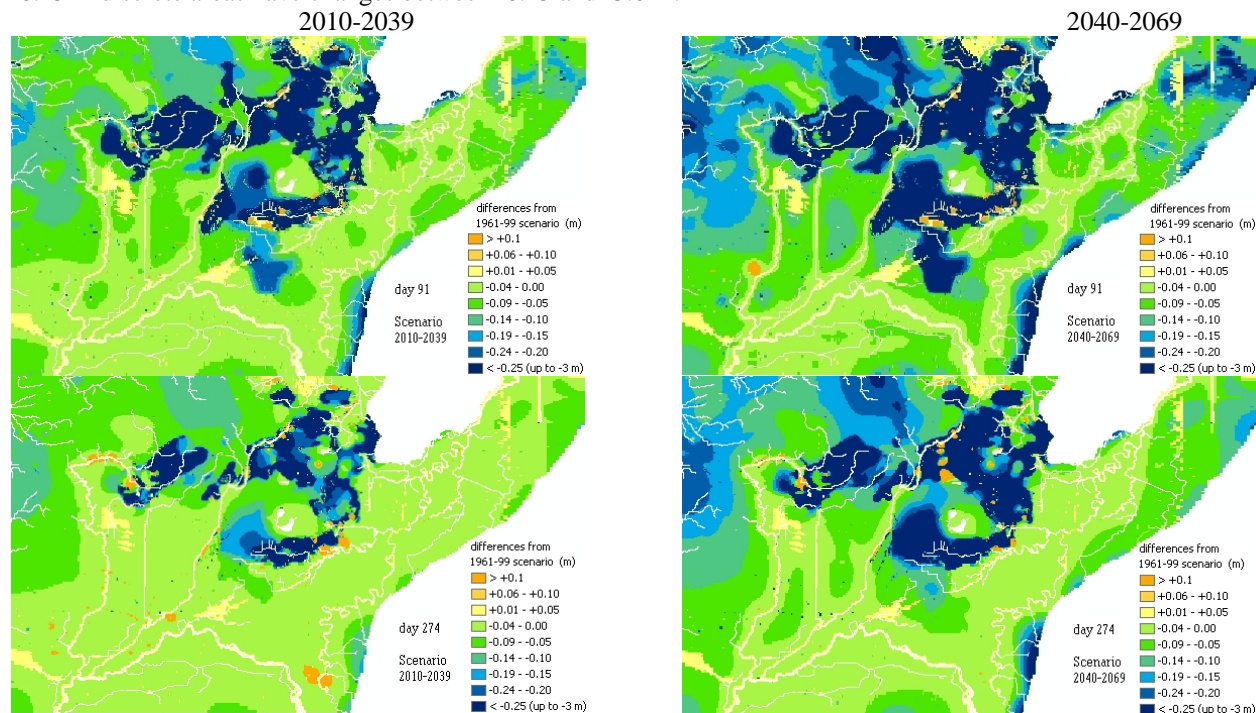


## Conclusions

Recharge to the Abbotsford-Sumas aquifer is predicted to decrease by 5.6 to 6.3% relative to historic values under climate change for the 2010-2039 scenario, resulting in a spatially-variable reduction in water levels ranging from 0.05 m to more than 0.25 m in most upland areas. For the 2040-2069 time periods, recharge decreases by 12.7 to 14.6% relative to historic values, resulting in water level declines greater than 0.25 m in most upland areas. These lower water levels will result in a reduction in hydraulic gradients from recharge to discharge areas, and a

consequent reduction in groundwater discharge that would translate to a reduction in baseflow in streams fed by groundwater. Because upland streams were assigned as constant head boundary conditions, the model does not predict significant changes in areas adjacent to the streams nor to the streams themselves. Improvements to the model should consider changes in hydrology as a consequence to climate change, but more site-specific information on the streams and refinement of the model in those areas is needed.

# References

Allen D.M., J. Scibek, P. Whitfield, and M. Wei, 2004, *Climate Change and Groundwater: Summary Repor*". Final report to Natural Resources Canada, Climate Change Action Fund.

Armstrong J.E., 1981, Post-Vashon Wisconsin Glaciation, Fraser Lowland, British Columbia. *Geological Survey Bulletin* 322.

Changnon S.A., F.A. Huff, and C.-F. Hsu, 1988, Relations between precipitation and shallow groundwater in Illinois, *Journal of Climate*, **1**:1239-1250.

Clague J.J., J.L. Luternauer, P.A. Monahan, K.A. Edwardson, S.R. Dallimore, and J.A. Hunter, 1998, Quaternary stratigraphy and evolution of the Fraser Delta, *In*: J.W.H. Monger (ed.), *Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia*, Geological Survey of Canada Bulletin, **525**, pp.57-82

Cox, S.E., and S.C. Kahle, 1999, Hydrogeology, ground-water quality, and sources of nitrate in lowland glacial aquifers of Whatcom County, Washington, and British Columbia, Canada, Water-Resources Investigations Report 98-4195, US Geological Survey.

Easterbrook D.J., 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington, *Geological Society of America Bulletin*, **80,** pp. 2273-2286.

Flato, G.M., G.J. Boer, W.G. Lee, N.A., McFarlane, D. Ramsden, M.C. Reader, and A.J. Weaver, 2000, The Canadian Centre for Climate Modeling and analysis Global Coupled Model and its climate, *Climate Dynamics,* **16**:451-467.

Halstead, E.C., 1977, *Hydrogeology, Fraser Valley*, Report Series - Inland Waters Directorate, Water Resources Branch, Canada, **55**:86-87.

Hamilton T.S., and B.D. Ricketts, 1994, Contour map of the sub-Quaternary bedrock surface, Strait of Georgia and Fraser Lowland, In: J.W.H. Monger (ed.), *Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia*, Geological Survey of Canada Bulletin, **481**, pp. 193-196.

Jyrkama M.I., J.F. Sykes, and S.D. Normani, 2002, Recharge estimation for transient ground water modeling, *Ground Water*, **40**(6):639-649.

Kahle S.C., 1991, *Hydrostratigraphy and Groundwater Flow in the Sumas Area, Whatcom County, Washington*, unpublished MSc Thesis, Western Washington University, Bellingham, WA, United States.

Racsko P., L. Szeidl, and M. Semenov, 1991,A serial approach to local stochastic weather models, *Ecological Modelling*, **57**:27-41.

Ricketts B.D., L.E., Jackson, D.R. Halliwell, and S. Vanderberg, 1993, *Unconfined Aquifers, Fraser River Basin*, Geological Survey of Canada, Open File 2624, 23 maps.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton, 1994, *The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*. EPA/600/R-94/168b. Washington, DC, US Environmental Protection Agency.

Semenov M.A., and E.M. Barrow, 1997, Use of a stochastic weather generator in the development of climate change scenarios, *Climatic Change*, **35**:397-414.

WHI (Waterloo Hydrogeologic Inc.), 2000, WHI UnSat Suite User's Manual: 1-D Unsaturated Zone Groundwater Flow and Contaminant Transport Modeling using VLEACH, PESTAN, VS2DT, and HELP, Waterloo, Can.

WHI (Waterloo Hydrogeologic Inc.), 2000, Visual MODFLOW v 3.0: User Manual, Waterloo, Canada.

Whitfield, P.H., and E. Taylor, 1998, Apparent recent changes in hydrology and climate of coastal British Columbia, *In*: Y. Alila (ed.), *Mountains to Sea: Human Interactions with the Hydrologic Cycle*, Proceedings of the 51st Canadian Water Resources Conference, pp. 22-29.

Wilby, R.L., C.W. Dawson, and E.M. Barrow, 2002, SDSM – a decision support tool for the assessment of regional climate change impacts, *Environmental and Modelling Software*, **17**:145-157.

Yates D.S., G.B. Rajagopalan, and K.Strzepek, 2003, A technique for generating regional climate scenarios using a nearest-neighbor algorithm, *Water Resources Research*, **39**(7):1199 SWC 7.

Zektser I.S., H.A. Loaiciga, 1993, Groundwater fluxes in the global hydrologic cycle: past, present, and future, *Journal of Hydrology*, **144**:405-427.